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Characterization of the Rolling Resistance of Aftermarket Passenger Car Tires

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Technical Report

Characterization of the Rolling Resistance of Aftermarket Passenger Car Tires

By

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July 1984

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16. ABSTRACT

This report presents the results from a recent EPA test program in which the tire characteristics which may affect tire rolling resistance were examined. The results obtained from this test program appear to reliably indicate the rolling resistance of the tires tested. Fifty-four model lines of passenger car tires (252 tires total) were tested using the procedure outlined in "EPA Recommended Practice for the Determination of Rolling Resistance Coefficients." Strong correlations were found to exist between tire rolling resistance and the tire model line, a tire's construction type, and body cord. Little relationship was observed between a tire's price and rolling resistance and an inconclusive relationship was found between belt fiber and rolling resistance.

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I. Background

In the early 1980s, EPA began to investigate the effects of tire rolling resistance. The benefits of improved (i.e., lower) rolling resistance include: reduced vehicle fuel consumption, lowered exhaust emissions and possibly reduced discrepanies between EPA and on-road vehicle fuel economy.

The amount of fuel consumed by a vehicle is a direct function of the tires that are used.[1] Improvements in the rolling resistance of tires would significantly reduce the amount of fuel consumed daily in the United States.

Vehicle exhaust emissions also depend upon rolling resistance. A strong correlation exists between rolling resistance and oxides of nitrogen (NOx) emissions; NOx emissions increase with the use of tires having higher rolling resistance. Carbon monoxide (CO) emissions are also affected by tire rolling resistance; CO emissions increase with increases in tire rolling resistance. In the case of hydrocarbons (HC), a weak relationship exists between HC emissions and rolling resistance.[2]

Variations in tire rolling resistance may contribute to the differences between EPA-measured fuel economies and those observed by consumers. Part of this discrepancy may result from aftermarket tires having significantly different rolling resistance from the tires on the corresponding production and EPA certification vehicles.

II. Summary

The purpose of this program was to compare the rolling resistance of tire model lines within a sales-representative test matrix and to determine which tire characteristics influence rolling resistance.

The tires for this test program included all tires, as defined by manufacturer/brand name (i.e., Goodyear, Sears) and model (i.e., Arriva, Guardsman), that accounted for at least 1 percent of 1981 replacement market sales. Additional tires were selected to increase the representation of as many manufacturer/brand names as possible and to maximize the total fraction of the replacement market represented. The test matrix used consisted of 252 tires, from 20 different manufacturer/brand names and 54 different model lines. This matrix covered approximately 54 percent of the 1981 replacement market.

Significant correlations were found between a tire's rolling resistance and the tire model, construction type, and body cord. An inconclusive relationship was found between belt fiber and rolling resistance.

Comparisons were made between different tires based upon the mean rolling resistance coefficient (RRC) of the model. Table 1 lists the models tested and their construction type, in order of increasing mean RRC. The three models with the lowest rolling resistance were:

1. BF Goodrich Lifesaver XLM
2. Uniroyal Steeler
3. Delta Radial II

In the analysis of construction type, it was determined that average radial-ply tires have 20.2 percent lower rolling resistance than bias-belted tires and 26.0 percent lower than bias-ply.

The analysis of body cord showed, with a high level of statistical confidence ($p = 0.01$), that among steel-belted radial tires those having polyester body cords had 8.8 percent lower mean rolling resistance than those having rayon body cords.

The sample sizes available for analysis of the effect of belt fiber on rolling resistance were not, for all types of belt fiber, large enough to state definitely that the use of one type lowers tire rolling resistance. It was found that radial tires with steel + fiberglass belt fibers tended to have lower rolling resistance than those with fiberglass belt fibers and those with steel belt fibers; aramid belt fiber tended to have higher rolling resistance than the other types.

Little relationship was observed between a tire's price and its rolling resistance. That is, the price of a tire is not a good indication of its rolling resistance.

It was determined that rolling resistance results are consistent regardless of the date of manufacture (within a reasonable amount of time) or test date. However, it should be noted that: 1) all tires used in this program were purchased within a small amount of time, 2) all members of each model were purchased from the same supplier, and 3) only four or six tires of each model were tested. The above should be considered when interpreting the results of this analysis.

Table 1

Mean Rolling Resistance Coefficients ($\overline{RRC}$) by Models

Brand & Model	Construction	$\overline{RRC}$
BF Goodrich Lifesaver XLM	Radial	0.00979
Uniroyal Steeler	Radial	0.00997
Delta Radial II	Radial	0.01009
Laramie Glass Rider	Radial	0.01018
Atlas Silveraire	Radial	0.01035
Firestone Deluxe Champion Radial	Radial	0.01041
Michelin XWW	Radial	0.01048
Multi-Mile XL	Radial	0.01052
M. Ward Runabout	Radial	0.01055
General Steel Radial	Radial	0.01059
Uniroyal Tigerpaw	Radial	0.01067
Penney Mileagemaker Plus	Radial	0.01078
Goodyear Arriva	Radial	0.01087
Kelly-Springfield Navigator	Radial	0.01087
General Dual Steel III	Radial	0.01091
Multi-Mile Supreme	Radial	0.01097
Goodyear Custom Poly-Steel	Radial	0.01101
K-Mart KM-225	Radial	0.01104
Dayton Quadra	Radial	0.01109
Delta Durasteel	Radial	0.01110

Table 1 (cont'd.)

Mean Rolling Resistance Coefficients ($\overline{RRC}$) by Models

Brand & Model	Construction	$\overline{RRC}$
Firestone 721	Radial	0.01122
Dayton Blue Ribbon	Radial	0.01149
Penney Mileagemaker XP	Radial	0.01152
Firestone Trax 12	Radial	0.01167
Sears Road Handler 78	Radial	0.01177
Summit Steel	Radial	0.01176
Dunlop Goldseal	Radial	0.01186
M. Ward Grappler	Radial	0.01208
Sears Weather Handler	Radial	0.01212
Goodyear Tiempo	Radial	0.01227
Cooper Lifeliner (glass belt)	Radial	0.01228
Armstrong SXA	Radial	0.01232
Dunlop Generation IV	Radial	0.01249
Cooper Lifeliner (steel belt)	Radial	0.01261
Michelin XVS	Radial	0.01363
Goodyear Cushion Belt Polyglas	Bias-Belt	0.01371
Armstrong Coronet All-Season	Radial	0.01381
Kelly-Springfield Roadmark	Bias-Ply	0.01393
Sears SuperGuard	Bias-Belt	0.01409

Table 1 (cont'd.)

Mean Rolling Resistance Coefficients ($\overline{RRC}$) by Models

Brand & Model	Construction	$\overline{RRC}$
Goodyear Power Streak	Bias-Ply	0.01411
Laramie Easy Rider	Bias-Ply	0.01428
Firestone Deluxe Champion Bias-Ply	Bias-Ply	0.01431
M. Ward Road Guard CLM	Bias-Belt	0.01433
BF Goodrich Belted	Bias-Belt	0.01445
Sears Guardsman	Bias-Ply	0.01468
Dayton Deluxe 78	Bias-Ply	0.01477
Summit Supreme 120	Bias-Ply	0.01546
K-Mart Economizer	Bias-Ply	0.01549
Kelly-Springfield Benchmark	Bias-Ply	0.01558
K-Mart KM-78	Bias-Ply	0.01599
Cooper Trendsetter	Bias-Ply	0.01624
Atlas Cushionaire	Bias-Ply	0.01641
Multi-Mile Poly IV	Bias-Ply	0.01644
Uniroyal Fastrak Poly	Bias-Ply	0.01672

Finally, two tires were tested repeatedly throughout the program to check for any variations in the test results as a function of time. Only minute changes in the test results caused by time-dependent factors were observed, reflecting good test precision and repeatability.

III. Test Program Design

The test matrix emphasized market coverage and represented as many tire models as feasible. To ensure that the test matrix was representative of tire sales, detailed knowledge of the breakdown of the 1981 replacement tire market was needed. Because of the fragmentation and size of the replacement tire market, Smithers Scientific Services, Inc. (SSS) of Akron, Ohio was contracted to develop the test matrix. SSS is a testing, research and consulting corporation with extensive experience in research and testing of automotive tires.

EPA requested that SSS supply market data and suggest a test matrix. The matrix which SSS prepared was based on market survey data where available, on requests for data sent to tire manufacturers, and, in a few cases where data were not publicly available and were not released by tire manufacturers, through estimates by Smithers staff.

The SSS matrix included every tire model known or estimated to represent 1 percent or more of the total 1981 tire replacement market. If a brand name represented more than 1 percent of the total market, but no individual model of that brand represented more than 1 percent, then the two most popular models sold under that brand name were included in the matrix. The tires included in the SSS matrix represented approximately 56 percent of the total 1981 replacement market; 58 models were included.

This program had maximum resources of approximately 300 tests. Therefore, some method was necessary to distribute the test capability over the SSS matrix. A previous test program[3] had indicated good homogeneity among tires of one model, therefore, to emphasize market coverage, tires were selected from all of the models of the SSS matrix.

For each of 19 models having 1 percent or more of the market, six test tires were selected. For each of the 39 models having less than 1 percent of the market, four test tires were included. Because of the small sample sizes, statistical confidence in the results was somewhat lower in this region of the test matrix. However, this was judged acceptable since these tires represent a smaller segment of the market. The sample sizes of four and six provided sufficient

replicate testing to have good statistical confidence in the results from these tires. Statistical confidence in the sample sizes is discussed further in the section entitled "Results."

The tires chosen to represent each model were all of 14-inch nominal diameter. Tires marketed under the P-metric sizing were all P195/75R14, while alphanumerically sized tires were all E78-14 or ER78-14. These were projected to be the best selling sizes in the passenger car tire replacement market for 1982.[4]

The radial tires in the matrix represent about 70 percent of 1981 radial replacement sales, while non-radials represent only 37 percent of 1981 non-radial replacement sales. The lower number of non-radials tested was deemed acceptable because the percentage of radials sold in the replacement market was increasing when the matrix was designed and is still increasing.

The test matrix used in this program is shown in Table 2. Initially, 270 tires were to be tested, however, four models of the SSS matrix became unavailable during the course of the program. Therefore, the actual test matrix used contained 54 models rather than 58, and represented 252 tire tests, instead of 270.

As a means of checking for any variations in the test results as a function of time, two tires were chosen from the matrix to serve as "correlation" tires. These tires (Michelin XWW, P195/75R14) were the single best selling model included in the matrix, and alone represent 6 percent of 1981 replacement market sales. Each time that another group of tires (usually 30 to 40) was tested, these two Michelin tires were retested, and the results were compared to those obtained in earlier tests. These results, discussed in the section "Quality Control," characterize possible changes in the test results caused by calibration drift, lack of machine alignment maintenance, or other unknown time-dependent factors.

IV. Test Contractor

The actual testing of the tires in this program was conducted by Standards Testing Laboratories, Inc., (STL) of Massillon, Ohio. STL has had extensive experience in tire testing, including rolling resistance testing. STL has tested tires for the Department of Transportation's (DOT) Uniform Tire Quality Grading program, has conducted testing for tire industry firms, and has participated in round-robin rolling

Table 2

Tire Test Matrix

Tire Description[1,2]	Number of Tires Sampled
Michelin XWW Radial[3]	6
Firestone 721 Radial	6
Goodyear Custom Polysteel Radial	6
Goodyear Power Streak Bias	6
Sears Road Handler 78 Radial	6
Sears Weather Handler Radial	6
Goodyear Tiempo Radial	6
Goodyear Arriva Radial	6
BF Goodrich Lifesaver XLM Radial	6
Michelin XVS Radial	6
Sears Guardsman Bias	6
Goodyear Cushion Belt Polyglas Bias-Belted	6
BF Goodrich CLM Bias-Belted	6
Firestone Deluxe Champion Radial	6
General Dual Steel III Radial	6
Uniroyal Steeler Radial	6
General Steel Radial	6
Sears Super Guard Bias-Belted	6
Dunlop Generation IV Radial	4
Firestone Trax 12 Radial	4
Firestone Deluxe Champion Bias	4
K-Mart KM78 Bias	4
Multi-Mile Supreme Radial	4
Uniroyal Tiger Paw Radial	4
Cooper Trendsetter Bias	4
Multi-Mile XL Radial	4
Kelly-Springfield Navigator Radial	4
K-Mart Economizer Bias	4
Atlas Cushionaire Bias	4
Kelly-Springfield Benchmark Bias	4
Armstrong Coronet All-Season Radial	4
Dayton Blue Ribbon Radial	4
Dayton Quadra Radial	4
Dayton Deluxe 78 Bias	4
Multi-Mile Poly IV Bias	4
Atlas Silveraire Radial	4
Kelly-Springfield Roadmark Bias	4
Armstrong SXA Radial	4
Cooper Lifeliner Radial (steel belted)	4
Dunlop Gold Seal Radial	4
Laramie Easy Rider Bias	4
K-Mart KM-225 Radial	4
Uniroyal Fastrak Poly Bias	4

Table 2 (cont'd.)

Tire Test Matrix

Tire Description[1,2]	Number of Tires Sampled
Montgomery Ward Runabout All Season Radial	4
Cooper Lifeliner Radial (glass belted)	4
JC Penny Mileagemaker XP Radial	4
JC Penny Mileagemaker Plus Radial	4
Delta Radial II	4
Laramie Glass Rider Radials	4
Summit Supreme 120 Bias	4
Delta Durasteel Radial	4
Montgomery Ward Grappler All Season Radial	4
Montgomery Ward Road Guard Bias-Belted	4
Summit Steel Radial	4

Total: 252 individual tests, not including repeat correlation tests.

[1] The four models which became unavailable are:
BF Goodrich Lifesaver LXII Radial (4)
General Ameri-Sprint Bias Ply (4)
General Ameri-Sprint Bias Belted (4)
Uniroyal Fastrak Bias-Belted (4)

[2] All radial tires are P195/75R14, all bias-belted and bias-ply tires are E78-14 or ER78-14.

[3] Two of this sample are correlation tires and were retested periodically throughout the test program.

resistance test programs conducted by the Society of Automotive Engineers. Excellent correlations between tire test results obtained at STL, at the General Motors Proving Ground, and at the University of Michigan test laboratory have been demonstrated.[5] These correlations verify that observed variations in rolling resistance reflect differences in the test tires, not in the test labs or other undetermined factors.

V. Test Procedure

The test procedure used was the spindle-force method described in "EPA Recommended Practice for the Determination of the Rolling Resistance Coefficients," which is attached as Appendix A. The procedure is outlined below.

A. Test Equipment

The tires were tested using a 67.23-inch diameter tire dynamometer. This machine is equipped with a movable carriage, on which the tire/wheel assembly is mounted. This assembly applies the specified test load perpendicular to the test wheel. The tire and test wheel are then driven at the desired speed.

B. Break-In

A break-in procedure was required, since automobile tires undergo a slight, permanent growth (increased circumference) when first run under operating conditions. The break-ins were performed by installing the tires on the test machine under the standard test conditions (load, inflation pressure, and ambient temperature), and running the tire at 50 miles per hour (the standard test speed) for a minimum of one hour.

C. Test Conditions

Standard conditions for this test include an ambient temperature between 70°F and 80°F, and specific loads and inflation pressures. The cold inflation pressure is 32 psi for alphanumercially sized tires and 35 psi for P-metric sizes. The test load is defined as 80 percent of the Tire & Rim Association (T&RA) design load for the given tire, at the given cold inflation pressure. Since all tires were the same size, the test load on the tire was the same in all cases; the T&RA design load is 1400 pounds force (lbf),[6] thus the test load is 1120 lbf. Use of the same test load (within 5 lbf) on all of the tires permits direct comparisons to be made between the measured rolling resistances of different tires.

D. Thermal Conditioning

After the tire break-in is completed, the tire is left in the thermal environment of the test equipment for a minimum of three hours. At the end of this time, the inflation pressure is checked and readjusted to the prescribed cold inflation pressure, if necessary.

E. Tire Warm-Up

The tire/wheel assembly is then reinstalled on the test machine (if it was removed before thermal conditioning), loaded against the test surface at the specified test load, and run for at least 45 minutes. This allows the tire temperature and operating inflation pressure to reach equilibrium.

F. Test Measurements

When the warm-up is completed and with the tire/dynamometer system operating at the test speed of 50 mph, the following are measured and recorded: tire spindle force (which will be converted to rolling resistance force), normal load on the tire, ambient temperature, loaded tire radius, and final inflation pressure.

G. Parasitic Losses

A small amount of energy is absorbed parasitically by the test machine through bearing friction which may be inherent in the measurement. The parasitic losses must be subtracted from the spindle force to isolate the tire's rolling resistance.

To determine parasitic test machine losses, the load on the tire is reduced to a value just sufficient to maintain rotation at 50 mph without slippage (approximately 10 lbf); the spindle force is then measured. This value represents the parasitic test machine loss and is subtracted from the previously measured spindle force to yield the net spindle force.

H. Averaging Technique

An averaging technique was used to eliminate any possible effects of minute machine or tire misalignments. In this technique, developed by engineers at the General Motors Proving Grounds, the tire/dynamometer assembly is run both clockwise and counterclockwise. Spindle force readings are taken for each rotation direction and the parasitic losses are subtracted from each value, as described above. The two values of net spindle force are then averaged to obtain the final spindle

force value. This averaging removes any systematic directional bias which might exist in the machine or measurement system. This is a slight deviation from the EPA Recommended Practice given in Appendix A, however, it is a desirable refinement for machines using the spindle-force method.

VI. Data Reduction

After averaging the net spindle forces to obtain the final spindle force, the final spindle force must be converted to a rolling resistance (or energy dissipation) force. This is a necessary force conversion, and is not a correction for equivalent flat-surface rolling resistance. The conversion is given by the equation:[7]

$$F_d = F_x (1 + r/R) \quad (1)$$

where:

F_x = final spindle force

r = loaded tire radius

R = test surface radius (33.615 in.)

F_d = rolling resistance force.

Since all of the tires tested in this program were of similar sizes and load ranges, and were loaded to 1120±5 lbf, comparisons between different tires may be made on the basis of rolling resistance force. However, more general comparisons between tires having different load ranges, aspect ratios, or nominal diameters must be made on the basis of their rolling resistance coefficients (RRC). The dimensionless RRCs are obtained by dividing the rolling resistance force F_d by the normal load on the tire during the test, L:

$$RRC = F_d/L \quad (2)$$

Computation of the tire RRCs was the extent of the data reduction conducted by STL. A sample STL data sheet, showing all of the information discussed so far, is included as Table 3.

The rolling resistance of an automobile tire is also dependent on the ambient temperature. The effect of temperature on rolling resistance is small as long as the ambient temperatures remain within a relatively narrow range: 70-80°F. All tests in this program were conducted within this temperature range, and the rolling resistance corrected to standard temperature (75°F) using the following correction formula:

Table 3

POWER LOSS/ROLLING RESISTANCE TEST

STL STANDARD TESTING LABORATORIES INC.
P.O. BOX 592 • 1845 HARSH AVE., S.E. • MASSILLON, OHIO 44646
Massillon Telephone: (216) 833-8548
Direct Akron Telephone: (216) 253-1901

CUSTOMER EPA
TEST TECHNICIAN D. Langman
STL JOB NO. J1-285
TEST NO. EPAR 347 (4243)
CHECKED BY D. L. Fuller

TIRE SIZE P195/75R14
TIRE BRAND Goodyear
TIRE SERIAL NO. MDKATK0422
TIRE NAME Tiempo

TEST RIM SIZE & CONTOUR 14 x 5.50
DATE June 22, 1983
TIRE CONSTRUCTION

TIRE LOAD lbs. (Fz)	TEST PRESSURE PSI.	TIRE ROLL. RADIUS In. (r)	TEST SPEED mph	AMBIENT TEMP. F°	NET SPINDLE FORCE CCW (F1)	NET SPINDLE FORCE CW (F2)	$\frac{F_1 + F_2}{2}$	ROLLING RESISTANCE lbs. (FR)	REGRESSION VALUE	ROLLING RES. COEF. lbs. (FR
1122	39.3	11.76	50.0	76	+9.8	-10.5	-.35	13.70.		.0122

80-147

$$F_d^* = F_d\,[1 + c_t\,(t_x - t_s)], \qquad (3)$$

where:

F_d^* = temperature-corrected rolling resistance force

F_d = uncorrected rolling resistance force

t_s = the standard test temperature (75°F)

t_x = the measured test ambient temperature

c_t = the temperature correction coefficient (3.3×10^{-3}/°F).

The relationship between rolling resistance and temperature within the specified temperature range is linear. However, the function may vary among tires of different construction or made with different materials. Therefore, when using the temperature correction formula, one must develop the temperature correction coefficient based on knowledge of the tire types and materials being used. The temperature correction coefficient (c_t) represents the amount of change in rolling resistance corresponding to a change in temperature of one degree Fahrenheit. For this test program, it was determined that 3.3×10^{-3} was the optimal value for c_t.[6]

Explanations of the details of data reduction methods used with rolling resistance data can be found in reference [7].

VII. Statistical Analysis

The data from the rolling resistance tests of 252 tires were analyzed to learn which characteristics affect rolling resistance using an analysis of variance. This analysis tests the hypothesis that N given population means are the same (i.e., the null hypothesis) against the alternate hypothesis that, for at least two of the tires tested, the means are unequal. Rejection of the null hypothesis is evidence that variation in rolling resistance is based on the tire characteristic. The significance of rejecting the null hypothesis is stated in terms of the probability of being incorrect by doing so. This probability leads to the percentage level of confidence that one can state that a tire characteristic has an effect on rolling resistance. The confidence levels given in the following discussion signify that the mean rolling resistance of a subset of tires sharing a characteristic (e.g., a subset of radials) does not equal the mean rolling resistance of the entire group of tires. Hence, the tire characteristic affects rolling resistance and a relationship exists.

An analysis of variance, as described in the previous paragraph, was performed for each of the following characteristics:

1. Model
2. Construction type
3. Body cord
4. Belt fiber

To investigate the consistency of tire manufacture as it affects rolling resistance, the means from the same models which had been manufactured at least one week apart were compared. To determine whether the price of a tire is related to its rolling resistance, a linear regression between purchase price and rolling resistance was performed. Finally, the standard deviations for all model lines tested were examined to determine the reliability of the test results.

VIII. Results

The results for all 252 tires tested are shown in Appendix B. Table 4 provides an overview of all tire characteristics examined and their effects on rolling resistance; Tables 5-9 show the results of each of the analyses performed.

A. Model

Through an analysis of variance of the 252 tires from 20 different companies constituting the final matrix, a relationship between model and rolling resistance was observed, with 99 percent confidence.

Mean RRC was calculated for each model. The three models with the lowest rolling resistance were:

1. BF Goodrich Lifesaver XLM
2. Uniroyal Steeler
3. Delta Radial II

The three models with the highest rolling resistance were:

1. Atlas Cushionaire
2. Multi-Mile Poly IV
3. Uniroyal Fastrak Poly

Table 5 lists, in increasing order, the rolling resistance force and mean RRC for each model tested, and other statistical results of this analysis.

Table 4

Summary of Effects of
Tire Characteristics On Rolling Resistance

Tire Characteristics	Sample Used	Result Observed
Model	170 radial tires from 20 companies	° Identity of model affects RRC. Models with lowest RRC: BF Goodrich Lifesaver XLM Uniroyal Steeler Delta Radial II
	60 bias-ply tires from 12 companies	° Identity of model affects RRC. Models with lowest RRC: Goodyear Power Streak Laramie Easy Rider Firestone Deluxe Champion
	22 bias-belted tires from 4 companies	° Identity of model affects RRC. Models with lowest RRC: Goodyear Cushion Belt Polyglas Sears Super Guard
Construction	All tires tested.	° Radial plies had 20.3% lower mean RRC than bias-belted tires and 26.1% lower mean RRC than bias-ply tires.

Table 4 (cont'd)

Summary of Effects of
Tire Characteristics On Rolling Resistance

Tire Characteristics	Sample Used	Result Observed
Body Cord	Steel-belted radials only	∘ Polyester body cord had 8.8% lower mean RRC than rayon body cord.
Belt Fiber	Radial-ply only	∘ Steel + fiberglass -belted had 0.081% lower mean RRC than fiber-glass-belted tires, 1.27% lower mean RRC than steel -belted tires, and 13.93% lower mean RRC than aramid-belted tires.
Price	All construction types	∘ Rolling resistance is not linearly dependent on price
Rolling Resistance Consistency Over Time	4 groups of two models of steel-belted radials made in different weeks	∘ RRC remains constant with date of manu-facture.

Table 5

Rolling Resistance Data - Means by Brand and Model

Brand and Model	N	Const.[1]	Rolling Resistance Force (lbf)		RRC		90% Confidence Interval around RRC[4]
			$\bar{x}$[2]	s [3]	$\bar{x}$	s	
BF Goodrich Lifesaver XLM	6	R	10.96	0.20014	0.00979	0.00018	0.00964-0.00994
Uniroyal Steeler	6	R	11.15	0.46529	0.00997	0.00042	0.00963-0.01031
Delta Radial II	4	R	11.30	0.23200	0.01009	0.00020	0.00985-0.01032
Laramie Glass Rider	4	R	11.41	0.12100	0.01018	0.00011	0.01005-0.01031
Atlas Silveraire	4	R	11.61	0.06300	0.01035	0.00007	0.01270-0.010430
Firestone Deluxe Champion Radial	6	R	11.67	0.25300	0.01041	0.00023	0.01023-0.01060
Michelin XWW	6	R	11.75	0.10700	0.01048	0.00010	0.01040-0.01056
Multi-Mile XL	4	R	11.79	0.24400	0.01052	0.00021	0.01028-0.01077
M. Ward Runabout	4	R	11.84	0.15800	0.01055	0.00014	0.01033-0.01067
General Steel Radial	6	R	11.85	0.40450	0.01059	0.00035	0.01029 0.01088
Uniroyal Tigerpaw	4	R	11.93	0.30522	0.01067	0.00026	0.01036-0.01098
Penney Mileagemaker Plus	4	R	12.08	0.15100	0.01078	0.00014	0.01061-0.01095
Goodyear Arriva	6	R	12.16	0.23811	0.01087	0.00022	0.01069-0.01105
Kelly-Springfield Navigator	4	R	12.18	0.02563	0.01087	0.00023	0.01060-0.01114

Table 5 (cont'd.)

Rolling Resistance Data - Means by Brand and Model

Brand and Model	N	Const.[1]	Rolling Resistance Force (lbf)		RRC		90% Confidence Interval around RRC[4]
			$\bar{x}$ [2]	s [3]	$\bar{x}$	s	
General Dual Steel III	6	R	12.22	0.28700	0.01091	0.00025	0.01071-0.01112
Multi-Mile Supreme	4	R	12.28	0.16800	0.01097	0.00014	0.01080-0.01113
Goodyear Custom Poly-Steel	6	BB	12.34	0.16967	0.01101	0.00016	0.01088 0.01113
K-Mart KM-225	4	R	12.37	0.21700	0.01104	0.00020	0.01081-0.01127
Dayton Quadra	4	R	12.41	0.22400	0.01109	0.00019	0.01086-0.01131
Delta Durasteel	4	R	12.46	0.13800	0.01110	0.00013	0.01095-0.01126
Firestone 721	6	R	12.58	0.21500	0.01122	0.00017	0.01108-0.01136
Dayton Blue Ribbon	4	R	12.87	0.14400	0.01149	0.00013	0.01134-0.01165
Penney Mileagemaker XP	4	R	12.92	0.23300	0.01152	0.00021	0.01123-0.01172
Firestone Trax 12	4	R	12.52	0.08810	0.01167	0.00009	0.01107-0.01127
Summit Steel	4	R	13.17	0.35400	0.01176	0.00032	0.01139-0.01214
Sears Road Handler 78	6	R	13.18	0.08900	0.01177	0.00008	0.01170-0.01183
Dunlop Goldseal	4	R	13.28	0.15300	0.01186	0.00015	0.01169-0.012044
M. Ward Grappler	4	R	13.54	0.93100	0.01208	0.00083	0.01110-0.01306
Sears Weather Handler	6	R	13.60	0.26900	0.01212	0.00025	0.01192-0.01233

Table 5 (cont'd.)

Rolling Resistance Data - Means by Brand and Model

Brand and Model	N	Const.[1]	Rolling Resistance Force (lbf)		RRC		90% Confidence Interval around RRC[4]
			$\bar{x}$ [2]	s [3]	$\bar{x}$	s	
Goodyear Tiempo	6	R	13.74	0.33482	0.01227	0.00028	0.01204-0.01250
Cooper Lifeliner (glass belt)	4	R	13.76	0.04900	0.01228	0.00005	0.01222-0.01233
Armstrong SXA	4	R	13.80	0.06700	0.01232	0.00005	0.01227-0.01238
Dunlop Generation IV	4	R	14.00	0.35800	0.01249	0.00032	0.01211-0.01287
Cooper Lifeliner (steel belt)	4	R	14.13	0.19500	0.01261	0.00017	0.01241-0.01280
Michelin XVS	6	R	14.59	0.09600	0.01363	0.00011	0.01354-0.01372
Goodyear Cushion Belt Polyglas	6	BB	15.35	0.16012	0.01371	0.00013	0.01360 0.01382
Armstrong Coronet All-Season	4	R	15.48	0.13700	0.01381	0.00014	0.01365-0.01397
Kelly-Springfield Roadmark	4	BP	15.62	0.31470	0.01393	0.00027	0.01361-0.01425
Sears SuperGuard	6	BB	15.80	0.25700	0.01409	0.00023	0.01390-0.01428
Goodyear Power Streak	6	BP	15.80	0.37244	0.01411	0.00036	0.01381-0.01440
Laramie Easy Rider	4	BP	16.00	0.52600	0.01428	0.00047	0.01372-0.01483
Firestone Deluxe Champion Bias-Ply	4	BP	16.04	0.29000	0.01431	0.00027	0.01399-0.01462
Montgomery Ward Road Guard	4	BB	16.08	0.21200	0.01433	0.00018	0.01411-0.01455

Table 5 (cont'd.)

Rolling Resistance Data - Means by Brand and Model

Brand and Model	N	Const.[1]	Rolling Resistance Force (lbf)		RRC		90% Confidence Interval around RRC[4]
			$\bar{x}$ [2]	s [3]	$\bar{x}$	s	
BF Goodrich Belted CLM	6	BB	16.18	0.09930	0.01445	0.00008	0.01438-0.01452
Sears Guardsman	6	BP	16.46	0.47700	0.01468	0.00043	0.01433-0.01503
Dayton Deluxe 78	4	BP	16.55	0.11100	0.01477	0.00008	0.01467-0.01486
Summit Supreme 120	4	BP	17.30	0.25400	0.01546	0.00021	0.01521-0.01570
K-Mart Economizer	4	BP	17.35	0.13600	0.01549	0.00014	0.01533-0.01565
Kelly-Springfield Benchmark	4	BP	17.21	0.87260	0.01558	0.00035	0.01517-0.01600
K-Mart KM-78	4	BP	17.92	0.21100	0.01599	0.00020	0.01575-0.01623
Cooper Trendsetter	4	BP	18.21	0.54700	0.01624	0.00048	0.01568-0.01680
Atlas Cushionaire	4	BP	18.40	0.50300	0.01641	0.00045	0.01587-0.01694
Multi-Mile Poly IV	4	BP	18.41	0.08700	0.01644	0.00007	0.01635-0.01653
Uniroyal Fastrak Poly	4	BP	18.71	0.71616	0.01672	0.00061	0.01600-0.01743
Combined	252		13.96	2.214	0.01248	0.00199	0.01227-0.01261

[1] Construction type:
R = radial-ply
BB = bias-belted
BP = bias-ply

[2] $\bar{x}$ = mean

[3] s = standard deviation

[4] 90 percent confidence interval means that one has 90 percent "confidence" that the variance of RRC is within the given limits.

B. Construction Type

All rolling resistance data were stratified by construction type and the mean for each type calculated. Table 6 shows the results.

A definite relationship between construction type and rolling resistance was observed. Of the three construction types tested (radial-ply; bias-belted; and bias-ply), the rolling resistance mean of radial-ply (N = 170) was 20.2 percent lower than bias-belted (N = 22) and 26.0 percent lower than bias-ply (N = 60). This relationship was observed with 99.9 percent confidence and confirmed previous findings.[3]

C. Body Cord

It was observed with 99.9 percent confidence that, among steel-belted radials, a relationship exists between body cord and rolling resistance. Tires of two different body cords were tested: polyester and rayon. Steel-belted radials with polyester body cord had lower mean rolling resistance (RRC = 0.011121, N = 100) than steel-belted radials with rayon body cord (RRC = 0.012100, N = 12). Table 7 shows the mean RRC for the two types of body cord.

Comparisons were made to test for the effect of body cord on rolling resistance only for steel-belted radials because all other types of tire were made exclusively of polyester body cord.

D. Belt Fiber

A relationship was observed, subject to the caveats given below, between the type of belt material in radial tires and its rolling resistance. Among radials, tires made with four different belt materials were tested: steel, fiberglass, aramid and steel + fiberglass. Steel + fiberglass-belted radials (N = 4) had the lowest mean rolling resistance followed by fiberglass-belted (N = 40), steel-belted (N = 110), and lastly, aramid-belted radials (N = 4). Table 8 shows the mean RRC and mean rolling resistance force for radial tires of different belt types.

One should note the small sample size of the above groups in interpreting these results. Although steel + fiberglass-belted and aramid-belted tires had the lowest and highest mean rolling resistance, respectively, only one model (four tires) was tested in each sample. Therefore, the observation really is only that the steel + fiberglass tires of one manufacturer were of slightly lower rolling resistance than the steel-belted tires of many manufacturers. The same can be said for aramid-belted tires. Thus, a larger sample is needed before any statistically valid conclusions are reached regarding the relative rolling resistance of steel + fiberglass- and aramid-belted tires.

Table 6

Rolling Resistance Data - Means by Construction

Construction	N	Rolling Resistance Force (lbf)		RRC		90% Confidence
		$\bar{x}$[1]	s[2]	$\bar{x}$	s	Interval around RRC[3]
Radial	170	12.62	1.059	0.01128	0.00099	0.01116-0.01141
Bias-belted	22	15.83	0.377	0.01413	0.00033	0.01401-0.01425
Bias-ply	60	17.07	1.1128	0.01525	0.00099	0.01504-0.01547
Combined	252	13.96	2.214	0.01248	0.00199	0.01227-0.01268

[1] $\bar{x}$ = mean
[2] s = standard deviation
[3] 90 percent confidence interval means that one has 90 percent "confidence" that the mean RRC of all tires of the specified category is within the given limits.

Table 7

Rolling Resistance Data - Means by Body Cord
(Steel-Belted Radials Only)[1]

Body Cord	Force (lbf)			RRC	
	N	$\bar{x}$	s	$\bar{x}$	s
Polyester	100	12.456	.8996	0.011121	0.000798
Rayon	12	13.221	1.5040	0.012100	0.001666
Combined	112	12.538	1.0012	0.011226	0.000968

[1] Only steel-belted radials were examined for the effect of body cord on rolling resistance, since all other types of tires were made exclusively of polyester body cord.

Table 8

Rolling Resistance Data - Means by Belt Fiber
(Radial Construction Only)[1]

Belt Fiber	Rolling Resistance Force (lbf)			RRC	
	N[2]	$\bar{x}$	s	$\bar{x}$	s
Steel + Fiberglass	4	12.437	.14307	0.011085	0.000134
Fiberglass	40	12.434	.94363	0.011094	0.000842
Steel	112	12.538	1.00120	0.011226	0.000967
Aramid	4	14.151	.27535	0.012629	0.000243
Combined	160	12.550	.99416	0.011225	0.000939

[1] Only radial tires were used in this analysis because among the 22 bias-belted tires, 12 were fiberglass-belted, and for 10 tires the information was not obtained. Bias-ply tires were not used in the analysis since they do not contain belts.

[2] Of 170 radials tested, only 160 were examined because the information was not obtained for 10 tires.

It should also be noted that while steel + fiberglass radials and fiberglass radials had the lowest mean rolling resistance, the three models with the lowest rolling resistance were steel belted (BF Goodrich Lifesaver XLM, Uniroyal Steeler and Delta Radial II). Furthermore, although steel + fiberglass-belted radials had the lowest mean RRC, the mean rolling resistance force of fiberglass-belted radials was slightly lower than steel + fiberglass-belted radials. Thus, the relationship between rolling resistance and belt fiber is not as conclusive as the others mentioned above.

E. Price

A linear regression of purchase price (1981 prices) against rolling resistance was performed for each of the three construction types to determine whether a relationship exists. It was observed for all types that tire price is not linearly dependent upon rolling resistance. That is, rolling resistance cannot be predicted by the price of a tire. Price accounts for only 10.8 percent of the variation in radial tires, 2.6 percent in bias-ply tires, and 8.7 percent of the variation in bias-belted tires. These results agree with an earlier analysis.[3] Table 9 lists all model lines, in order of increasing mean RRC, and the purchase price of each tire.

F. Rolling Resistance Consistency Over Time

It was concluded from the examination that rolling resistance is consistent over time and thus the rolling resistance test results reliably predict the rolling resistance of any tire from a particular model. To determine this, models were examined which were identical in every way except that they were manufactured on different dates (as indicated by the DOT tire identification). Table 10 gives the details of this examination.

The mean RRC of two models, each containing two groups of tires manufactured during different weeks, were examined. Tires of the first model, a steel-belted radial, were manufactured during the weeks of November 2-8, 1980, and February 8-14, 1981. The difference between the means of these two groups is 0.00004 and the pooled standard deviation (i.e., the standard deviation for the entire model) of the model is 0.00014. Tires of the second model, also a steel-belted radial, were made during the weeks of May 9-15 and May 30-June 5, 1982. The difference between the means of these two groups is 0.00023 and the pooled standard deviation is 0.00017. The means of the first model were not different at the 99 percent confidence level; the means of the second model were not different at the 95 percent confidence level. These figures are very consistent for the two models, and demonstrate that the rolling resistance of a tire could be relied upon as a stable manufacturing parameter, based upon our testing.

Table 9

Mean RRC and Purchase Price

Brand and Model	$\overline{RRC}$	Price*
BF Goodrich Lifesaver XLM	0.00979	$ 49.94
Uniroyal Steeler	0.00997	57.72
Delta Radial II	0.01009	47.60
Laramie Glass Rider	0.01018	45.75
Atlas Silveraire	0.01035	57.03
Firestone Deluxe Champion Radial	0.01041	47.17
Michelin XWW	0.01048	86.59
Multi-Mile XL	0.01052	46.95
Montgomery Ward Runabout	0.01055	80.08
General Steel Radial	0.01059	62.41
Uniroyal Tigerpaw	0.01067	54.39
JC Penney Mileagemaker Plus	0.01078	84.18
Goodyear Arriva	0.01087	67.13
Kelly-Springfield Navigator	0.01087	55.00
General Dual Steel III	0.01091	69.59
Multi-Mile Supreme	0.01097	49.94
Goodyear Custom Poly-Steel	0.01101	57.98
K-Mart KM-225	0.01104	60.97
Dayton Quadra	0.01109	39.47
Delta Durasteel	0.01110	43.70
Firestone 721	0.01122	62.17
Dayton Blue Ribbon	0.01149	51.64
JC Mileagemaker XP	0.01152	93.16
Firestone Trax 12	0.01167	55.44
Summit Steel	0.01176	42.87
Sears Road Handler 78	0.01177	117.49
Dunlop Goldseal	0.01186	54.95
Montgomery Ward Grappler	0.01208	109.08
Sears Weather Handler	0.01212	73.07
Goodyear Tiempo	0.01227	61.63
Cooper Lifeliner (glass belt)	0.01228	49.82
Armstrong SXA	0.01232	61.14
Dunlop Generation IV	0.01249	57.95
Cooper Lifeliner (steel belt)	0.01261	54.44

Table 9 (cont'd.)

Mean RRC and Purchase Price

Brand and Model	$\overline{RRC}$	Price*
Michelin XVS	0.01363	$ 90.00
Goodyear Cushion Belt Polyglas	0.01371	45.04
Armstrong Coronet All-Season	0.01381	63.83
Kelly-Springfield Roadmark	0.01393	41.00
Sears Super Guard	0.01409	60.07
Goodyear Power Streak	0.01411	41.25
Laramie Easy Rider	0.01428	34.21
Firestone Deluxe Champion Bias-Ply	0.01431	40.84
Montgomery Ward Road Guard	0.01433	69.08
BF Goodrich Belted CLM	0.01445	38.48
Sears Guardsman	0.01468	37.79
Dayton Deluxe 78	0.01477	28.62
Summit Supreme 120	0.01546	30.40
K-Mart Economizer	0.01549	34.97
Kelly-Springfield Benchmark	0.01558	38.00
K-Mart KM-78	0.01599	41.00
Cooper Trendsetter	0.01624	32.98
Atlas Cushionaire	0.01641	28.00
Multi-Mile Poly IV	0.01644	34.95
Uniroyal Fastrak Poly	0.01672	41.19

* Prices given may not be representative of current prices.

Table 10

Rolling Resistance Consistency Over Time -
Groups of Tires Manufactured During Different Weeks

Model 1

	N	Date of Manufacture	RRC	Standard Deviation
Group 1	2	Nov. 2-8, 1980	0.00979	0.00006
Group 2	4	Feb. 8-14, 1981	0.00975	0.00018
		Pooled standard deviation:		0.00014

Model 2

	N	Date of Manufacture	RRC	Standard Deviation
Group 1	2	May 9-15, 1982	0.01086	0.00016
Group 2	4	May 30-June 5,1982	0.01109	0.00012
		Pooled standard deviation:		0.00017

G. Reliability

To further determine how reliably the rolling resistance of an individual tire from a model line reflects the rolling resistance of the entire model line, the standard deviation of the models were examined. The standard deviation ranged from 0.00006 to 0.00058, with a mean of 0.00022. The coefficient of variation for each model was typically 2 percent. The 90 percent confidence interval about the mean was typically only ±0.00035. These figures signify that the sample sizes of four- and six were adequate to obtain sound statistics. These figures also indicate that testing only one tire of a given model gives a good indication of the mean rolling resistance of the model.

IX. Quality Control

Two tires (Michelin XWWs) served as correlation tires and were each tested seven times as a means of checking for any variations in the test results as a function of time. Only minute changes in the test results were observed caused by time-dependent factors such as calibration drifts, lack of machine alignment, or other unknown factors. The RRC for these tires ranged from 0.0105 - 0.0108. The pooled standard deviation of these tires' test results, for test dates ranging from July 6, 1982 to March 15, 1984, was 0.00009. The low standard deviations for the models (given on the previous page) and for the correlation tires reflect precision testing, consistent test conditions, and again demonstrates the predictability of rolling resistance for an individual tire if a tire of the same model has been tested.

X. Conclusions

A. Summary of Results

Based on the test results from 252 tire tests, it was determined that the following characteristics influence tire rolling resistance:

1. Model
2. Construction
3. Body cord

Belt fiber was also observed to have some influence on rolling resistance, but the sample size of different belt fibers and the variation within this sample were small.

It was concluded that neither price nor date of manufacture (within a reasonable amount of time) is related to a tire's rolling resistance. Finally, an examination of the standard deviations from all models tested and from the correlation tires showed precise, uniform testing and demonstrated the reliability of the rolling resistance test to forecast the rolling resistance of tire models by testing an individual tire of that model.

For the most part, the lowest rolling resistance characteristics examined were actually present in the test tires which received the lowest rolling resistance. That is, the statistically "best" tires generally did have the lowest rolling resistance values in the test program.

Based on this analysis, the most fuel-efficient tire appears to be:

1. Radial-ply, and to have
2. Polyster body cords.

The three lowest rolling resistance models were:

1. BF Goodrich Lifesaver XLM
2. Uniroyal Steeler
3. Delta Radial II.

All three of the above models were:

1. Radials,
2. Steel-belted with
3. Polyester body cord.

Examination of the predicted best tires versus the observed best tires indicate that the prediction is adequate for the major macroscopic parameters such as construction type and body cord.

B. Comparison with Previous Findings

This analysis agreed, for the most part, with earlier findings.[3] Both studies found a relationship between construction type, belt fiber, and manufacturer; both studies also found that tires are manufactured consistently. Neither study found a relationship between purchase price and rolling resistance. Table 11 summarizes the previous study's findings. The previous study did not find a correlation between body cord and rolling resistance, while this study found some weak correlation. This can, most likely, be attributed to the substantially larger sample size used in this analysis.

Table 11

Summary of Results from a Previous Study[3]--
Effects of Tire Characteristics On Rolling Resistance

Tire Characteristics	Sample Used	Result Observed
Manufacturer	86 tires from 19 companies	° Identity of the manufacturer does affect RRC.
Construction Type	13-inch tires	° Radials had 18.3% lower mean RRC than bias-belted and bias-ply tires.
	15-inch tires	° Radials had 27.5% lower mean RRC than bias-belted and 23.5% lower mean RRC than bias-ply tires.
Belt Fiber	13-inch radials	Fiberglass had 4.7% lower mean RRC than steel, 10.1% lower mean RRC than aramid and 24.2% lower RRC than rayon.
Body Cord	13-inch steel radials	° Does not affect RRC.
Price	13-inch radials	° Price is not linearly dependent on rolling resistance.
	13-inch bias-belted	° Price is not linearly dependent on rolling resistance.
	13-inch bias ply	° Price is not linearly dependent on rolling resistance.

Table 11 (cont'd.)

Summary of Results from a Previous Study[3]--
Effects of Tire Characteristics On Rolling Resistance

Tire Characteristics	Sample Used	Result Observed
RRC Consistency Over Time	3 groups of one model of bias ply tire made on different dates	• RRC of a model does not vary appreciably with date of manufacture.
	2 groups of one model of fiberglass radial made on different dates	• RRC of a model does not vary appreciably with date of manufacture.

References

1. "Tire Rolling Resistance and Vehicle Fuel Consumption," Glenn D. Thompson and Marty Reineman, U.S. EPA, SAE Paper No. 81068, February 1981.

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5. "Interim Report on the Characterization of the Rolling Resistance of Aftermarket Passenger Car Tires," Terry Newell, March 1983.

6. 1981 Yearbook and 1980 Yearbook, The Tire and Rim Association, Inc.

7. "The Measurement of Passenger Car Tire Rolling Resistance," SAE Information Report J1270, October 1979.

Appendix A

"EPA Recommended Practice for the Determination of Tire Rolling Resistance Coefficients"

EPA Recommended Practice for Determination of Tire Rolling Resistance Coefficients

Glenn Thompson

March 1980

Amended August 1980

Standards Development and Support Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Office of Air, Noise and Radiation
U.S. Environmental Protection Agency

I. Introduction

This test procedure determines the tire rolling resistance coefficient for a free rolling tire at a steady speed. This procedure conforms to the SAE Recommended Practice, Rolling Resistance Measurement Procedure for Passenger Car Tires - SAE J1269, generally adopting the recommended conditions of J1269 as the required standard conditions. The SAE Recommended Practice J1269 and the accompanying SAE information report J1270 may be consulted for additional information.

II. Test Equipment

The test equipment required is a tire dynamometer which measures the tire energy dissipative force as the tire is driven by a large cylindrical test wheel.

A. Tire Dynamometer

The test dynamometer shall be a cylindrical surface machine of 67.23 in (1.7076m) diameter. The test machine shall be capable of supplying a force on the tire perpendicular to the test surface, and shall be able to measure the transverse reaction forces acting on the tire or the torque necessary to drive the test wheel. During this process the machine must be capable of maintaining the test surface at constant speed. The width of the test surface must exceed the width of all test tires, and the test surface shall be coated with a medium coarseness abrasive (80 grit). As an example, medium grit 3M Safety-Walk represents a satisfactory surface.*

1. Test Machine Alignment

The direction of application of the tire load must be normal to the test surface within 0.03 deg (0.5 mrad). The wheel plan of the tire must be normal to the test surface within 0.03 deg (0.5 mrad) and parallel to the direction of motion of the test surface within 0.03 deg (0.5 mrad).

2. Test Machine Control Accuracy

Exclusive of perturbations induced by the tire and rim nonuniformities, the test equipment must control the test variables within the following limits:

	U.S. Customary Units	SI Units
Tire Load	5 lbf	22 N
Surface Speed	1 mph	2 km/h

* The manufacturer of this product is identified to clarify the example and does not imply endorsement of the product.

3. Test Machine Instrumentation Accuracy

The instrumentation used for readout and recording of test data must be accurate within the following tolerances:

	U.S. Customary Units	SI Units
Tire Load	2 lbf	8 N
Surface Speed	0.5 mph	0.8 km/h
Spindle Force	0.1 lbf	0.4 N
Loaded Radius	0.1 in	0.002 m

B. The Test Cell Requirements

The primary requirement for the test cell is that the ambient temperature be well controlled. In addition, the support services of compressed air should be available for tire inflation as should the necessary gauges to measure tire inflation.

1. Thermal Control

The ambient temperature in the vicinity of the test tire shall be 75 $\pm$ 5°F (24 $\pm$ 3°C).

2. Temperature Measurement Precision

The instrumentation used to measure the ambient temperature must be accurate to within 1 °F (0.5 °C). This instrumentation shall be located approximately 15 inches from the tire, measured perpendicular to the sidewall.

III. Test Procedure

The test procedure consists of the following steps: tire mounting; tire break-in; equilibration of the tire to the test ambient temperature; adjustment of the cold inflation pressure; tire warm-up and then measurement of the tire rolling resistance.

A. Tire Mounting

1. Rims

The tire shall be mounted on test rims which have an approved contour and width as specified by the Tire & Rim Association, Inc., as "design rim width" $\pm$ one half inch for the size tire being rested. For tire sizes not standardized by the Tire & Rim Association, Inc., reference should be made to the appropriate standardizing organization as listed in the Federal Motor Vehicle Safety Standards (CFR Title 49 §571.109 Table I). These rims shall have a maximum radial runout of 0.035 in (0.88 mm) and a maximum lateral runout of 0.045 in (1.1 mm).

2. Inflation Pressure

The inflation pressure of the tires after mounting shall be:

Alpha Numeric Size Tires	32 psi (220 kPa)
"P" Type tires	35 psi (240 kPa)

The tire inflation pressure after mounting shall be correct to within 1 psi (6.8 kPa). The gauges used to measure this tire inflation pressure shall be accurate to within 0.5 psi (3.4 kPa).

B. Tire Break-in

Tires may undergo significant permanent growth upon first operation and therefore may require an initial break-in and cooling period prior to the start of the test. A break-in run consisting of installing the tire on the tire test machine and operating the system under the test conditions for a period of 1 hour is recommended.

C. Thermal Conditioning

After initial break-in the tire shall be placed in the thermal environment of the test conditions for a minimum period of 3 hours before the test. During this period the tire inflation pressure should be checked and adjusted if necessary, to the design cold inflation pressure of the tire.

D. The Rolling Resistance Measurement

The test consists of a final pressure check, loading the tire, the tire warm-up, during which the tire temperature and inflation are allowed to increase as they would in typical service; followed by the rolling resistance measurement.

1. Installation on the Test Machine

The inflation pressure of the tire shall be checked and adjusted if necessary. The inflation pressure immediately prior to the test shall be correct to within 0.25 psi (1.7 kPa). The gauges used to determine this pressure shall be accurate to within 0.25 psi (1.7 kPa). The tire shall then be installed on the test machine if not already installed, and the load on the tire perpendicular to the test surface shall be adjusted to 80 percent of the design load of the tire.

2. Tire Warm-up

The test tire shall be conditioned by operation at a speed of 50 mph for a minimum of 45 minutes.

T_x = the test wheel drive torque of III D3.

T_p = the parasitic test wheel drive torque of III D4.

B. Tire Energy Dissipation Force

The tire energy dissipation force shall be calculated from the net spindle reaction force by the following equation:

$$F_d = f(1 + r/R) \quad (2)$$

Where:

F_d = the tire energy dissipation force lb (N),

F = the net tire spindle force lb (N),

r = the tire loaded radius, in (m),

R = the test surface radius, in (m).

In the case of the torque measurement method the energy dissipation force is to be calculated by:

$$F_d = T/R \quad (3)$$

3. Rolling Resistance Measurements

Following the tire warm-up and with the test dynamometer operating at 50 mph, the following parameters shall be recorded:

a. Tire spindle force or test wheel drive torque.
b. Normal load on the tire.
c. Loaded radius of the tire.

4. Measurement of Parasitic Losses

As a final measurement, the parasitic machine losses shall be determined. The test machine speed shall be maintained at 50 mph while the load onthe tire is reduced to approximately one percent of the test load. Under this condition the following parameters shall be determined:

a. Tire spindle force or test sheel drive torque.
b. Normal load on the tire.

IV. Data Analysis

The data reduction consists of the correction for the machine parasitic losses, conversion to a tire energy dissipation force, correction to the standard test temperature, and the computation of the tire rolling resistance coefficient.

A. Subtraction of Parasitic Losses

The spindle force or test wheel drive torque measurement of the machine parasitic losses obtained in III. D4, shall be subtracted from the spindle forces or test wheel drive torques measured during the test, III. D3, to obtain the net spindle reaction force or net drivewheel drive torque.

That is:

$$F = F_x - F_p \qquad (1)$$

$$T = T_x - T_p$$

Where:

F = the net spindle reaction force.

F_x = the spindle reactive force measured during the test, III. D3.

F_p = the parasitic spindle reactive force of III. D4.

T = the net test wheel drive torque.

C. Temperature Correction

The tire energy dissipation force shall be corrected to the standard test temperature of 75°F by the following equation:

$$F_d^* = F_d[1 + c_t(t_x - t_s)] \qquad (4)$$

F_d^* = the tire dissipative force at the standard temperature,

t_x = the average measured temperature over the duration of the test,

t_s = the standard test temperature 75°F (24°C),

c_t = the temperature correction coefficient, $5 \times 10^{-3}/°F$ ($9 \times 10^{-3}/°C$).

The test ambient temperature shall always be within 75° ± 5°F (24 ± 3°C), as described in II.B.1.; therefore, this linear temperature correction will always be applied over a temperature range of less than 5°F (3°C) for any one test.

D. Net Load Force

The parasitic load force measured in III D4 shall be subtracted from the normal load force measured during the test IIID3 to obtain the net load force.

That is:

$$L = L_x - L_p \tag{5}$$

Where:

L = the net load force,

L_x = the tire load force measured during the test III D3.

L_p = the tire load force during the parasitic measurement III D4.

E. Rolling Resistance Coefficient

The rolling resistance coefficient is calculated by dividing the energy dissipation force by the net load imposed in the tire:

$$C = F_d^*/L \tag{6}$$

Where:

C = rolling resistance coefficient (RRC).

Equations 1, 2, 4, 5, and 6 may be combined into the following single equation:

$$C = \frac{(F_x - F_p)(1 + r/R)[1 + c_t(t_x - t_s)]}{(L_x - L_p)} \tag{7}$$

Likewise, equations 1, 3, 4, 5, and 6 may be combined as:

$$C = \frac{(T_x - T_p)[1 + c_t(t_x - t_s)]}{R(L_x - L_p)} \tag{8}$$

Appendix B

Individual Tire Rolling Resistance Test Results

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4101	Armstrong Coronet All-Season Radial	10/27/82	15.62	0.01392	74	15.57	0.01388
4102	Armstrong Coronet All-Season Radial	10/27/82	15.29	0.01362	78	15.44	0.01375
4103	Armstrong Coronet All-Season Radial	10/28/82	15.50	0.01385	75	15.50	0.01385
4104	Armstrong Coronet All-Season Radial	10/28/82	15.50	0.01386	77	15.60	0.01396
4105	Armstrong SXA Radial	10/27/82	13.77	0.01228	74	13.72	0.01224
4106	Armstrong SXA Radial	10/27/82	13.90	0.01239	75	13.90	0.01239
4107	Armstrong SXA Radial	10/27/82	13.76	0.01230	75	13.76	0.01230
4108	Armstrong SXA Radial	10/27/82	13.77	0.01232	75	13.77	0.01232
4109	Atlas Cushionaire Bias	9/15/82	18.47	0.01648	75	18.47	0.01648
4110	Atlas Cushionaire Bias	9/15/82	19.05	0.01699	74	18.99	0.01694
4111	Atlas Cushionaire Bias	9/16/82	17.86	0.01592	73	17.74	0.01581
4112	Atlas Cushionaire Bias	9/16/82	18.20	0.01624	78	18.38	0.01640
4113	Atlas Silveraire Radial	9/23/83	11.56	0.01031	77	11.64	0.01038
4114	Atlas Silveraire Radial	9/29/83	11.56	0.01029	73	11.48	0.01023

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4115	Atlas Silveraire Radial	9/29/83	11.63	0.01035	78	11.75	0.01045
4116	Atlas Silveraire Radial	9/29/83	11.69	0.01045	75	11.69	0.01045
4117	Cooper Lifeliner Radial (Glass belt)	10/19/82	13.70	0.01221	78	13.84	0.01233
4118	Cooper Lifeliner Radial (Glass belt)	10/19/82	13.75	0.01230	77	13.84	0.01238
4119	Cooper Lifeliner Radial (Glass belt)	10/19/82	13.82	0.01232	78	13.96	0.01244
4120	Cooper Lifeliner Radial (Glass belt)	10/19/82	13.76	0.01229	72	13.62	0.01216
4121	Cooper Lifeliner Radial (Steel belt)	10/15/82	14.34	0.01277	77	14.43	0.01285
4122	Cooper Lifeliner Radial (Steel belt)	10/15/82	14.21	0.01268	77	14.30	0.01276
4123	Cooper Lifeliner Radial (Steel belt)	10/19/82	13.88	0.01238	75	13.88	0.01238
4124	Cooper Lifeliner Radial (Steel belt)	10/19/82	14.09	0.01259	77	14.18	0.01267
4125	Cooper Trendsetter	10/01/82	18.94	0.01687	78	19.13	0.01703
4126	Cooper Trendsetter	10/05/82	17.71	0.01577	77	17.83	0.01587

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4127	Cooper Trendsetter	10/07/82	17.88	0.01599	77	18.00	0.01610
4128	Cooper Trendsetter	10/07/82	18.29	0.01632	75	18.29	0.01632
4129	Dayton Blue Ribbon	10/21/82	12.71	0.01135	73	12.63	0.01127
4130	Dayton Blue Ribbon	10/21/82	12.99	0.01159	74	12.95	0.01155
4131	Dayton Blue Ribbon	10/21/82	12.78	0.01142	74	12.74	0.01138
4132	Dayton Blue Ribbon	10/21/82	12.99	0.01162	73	12.90	0.01154
4133	Dayton Deluxe 78 Bias	10/25/82	16.41	0.01468	78	16.57	0.01482
4134	Dayton Deluxe 78 Bias	10/25/82	16.53	0.01472	76	16.58	0.01477
4135	Dayton Deluxe 78 Bias	10/25/82	16.67	0.01486	76	16.73	0.01491
4136	Dayton Deluxe 78 Bias	10/25/82	16.60	0.01481	79	16.82	0.01500
4137	Dayton Quadra Radial	10/25/82	12.47	0.01113	75	12.47	0.01113
4138	Dayton Quadra Radial	10/25/82	12.66	0.01128	76	12.70	0.01132
4139	Dayton Quadra Radial	10/26/82	12.40	0.01110	75	12.40	0.01110
4140	Dayton Quadra Radial	10/26/82	12.12	0.01082	76	12.16	0.01086
4141	Delta Durasteel	10/14/82	12.58	0.01122	75	12.58	0.01122
4142	Delta Durasteel	10/14/82	12.37	0.01102	75	12.37	0.01102

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4143	Delta Durasteel	10/14/82	12.57	0.01120	74	12.53	0.01117
4144	Delta Durasteel	10/14/82	12.31	0.01096	74	12.27	0.01093
4145	Delta Radial II	10/13/82	11.23	0.01004	78	11.34	0.01014
4146	Delta Radial II	10/13/82	11.37	0.01015	77	11.45	0.01022
4147	Delta Radial II	10/13/82	11.57	0.01031	75	11.57	0.01031
4148	Delta Radial II	10/13/82	11.02	0.00984	78	11.13	0.00994
4149	Dunlop Generation IV	9/14/82	13.70	0.01221	75	13.70	0.01221
4150	Dunlop Generation IV	9/14/82	13.96	0.01248	75	13.96	0.01248
4151	Dunlop Generation IV	9/14/82	14.51	0.01294	74	14.46	0.01290
4152	Dunlop Generation IV	9/14/82	13.82	0.01233	76	13.87	0.01237
4153	Dunlop Goldseal	5/27/83	13.47	0.01205	76	13.51	0.01209
4154	Dunlop Goldseal	5/27/83	13.13	0.01170	74	13.09	0.01166
4155	Dunlop Goldseal	5/27/83	13.19	0.01179	74	13.15	0.01175
4156	Dunlop Goldseal	5/27/83	13.34	0.01192	75	13.34	0.01192
4157	Firestone 721	9/16/83	12.70	0.01130	73	12.62	0.01122
4158	Firestone 721	9/16/83	12.29	0.01099	75	12.29	0.01099

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4159	Firestone 721	9/16/83	12.42	0.01112	75	12.42	0.01112
4160	Firestone 721	9/16/83	12.49	0.01111	78	12.61	0.01122
4161	Firestone 721	9/16/83	12.83	0.01141	74	12.79	0.01138
4162	Firestone 721	9/16/83	12.77	0.01137	76	12.81	0.01141
4163	Firestone Deluxe Champion Radial	9/16/83	11.71	0.01047	73	11.63	0.01040
4164	Firestone Deluxe Champion Radial	9/16/83	11.51	0.01025	74	11.47	0.01022
4165	Firestone Deluxe Champion Radial	9/22/83	11.85	0.01059	78	11.97	0.01069
4166	Firestone Deluxe Champion Radial	9/22/83	11.44	0.01022	74	11.40	0.01019
4167	Firestone Deluxe Champion Radial	9/22/83	12.07	0.01076	76	12.11	0.01079
4168	Firestone Deluxe Champion Radial	9/22/83	11.45	0.01020	77	11.53	0.01026
4169	Firestone Deluxe Champion Bias	9/22/83	16.10	0.01435	78	16.26	0.01449
4170	Firestone Deluxe Champion Bias	9/22/83	16.16	0.01445	78	16.32	0.01460

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4171	Firestone Deluxe Champion Bias	9/22/83	15.62	0.01392	79	15.83	0.01411
4172	Firestone Deluxe Champion Bias	9/23/83	16.28	0.01451	76	16.33	0.01456
4173	Firestone Trax 12	9/23/83	12.62	0.01128	78	12.74	0.01139
4174	Firestone Trax 12	9/23/83	12.55	0.01119	75	12.55	0.01119
4175	Firestone Trax 12	9/23/83	12.42	0.01108	79	12.58	0.01123
4176	Firestone Trax 12	9/23/83	12.47	0.01112	76	12.51	0.01116
4185	General "Steel" Radial	9/29/83	11.82	0.01058	78	11.94	0.01069
4186	General "Steel" Radial	9/29/83	12.64	0.01128	79	12.81	0.01142
4187	General "Steel" Radial	9/29/83	11.69	0.01043	74	11.65	0.01039
4188	General "Steel" Radial	9/29/83	11.81	0.01054	78	11.93	0.01064
4189	General "Steel" Radial	9/29/83	11.68	0.01044	75	11.68	0.01044
4190	General "Steel" Radial	9/30/83	11.48	0.01026	77	11.56	0.01033
4191	General Dual Steel III	6/16/83	12.44	0.01110	77	12.52	0.01117
4192	General Dual Steel III	6/16/83	12.37	0.01105	75	12.37	0.01105
4193	General Dual Steel III	6/16/83	12.43	0.01110	75	12.43	0.01110

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4194	General Dual Steel III	6/16/83	11.68	0.01045	72	11.56	0.01034
4195	General Dual Steel III	6/16/83	12.15	0.01083	74	12.11	0.01079
4196	General Dual Steel III	6/16/83	12.24	0.01095	75	12.24	0.01095
4197	BF Goodrich CLM	6/16/83	16.15	0.01443	79	16.36	0.01462
4198	BF Goodrich CLM	6/17/83	16.23	0.01448	78	16.39	0.01462
4199	BF Goodrich CLM	6/17/83	16.30	0.01455	75	16.30	0.01455
4200	BF Goodrich CLM	6/17/83	16.01	0.01432	77	16.12	0.01441
4201	BF Goodrich CLM	6/20/83	16.15	0.01442	74	16.10	0.01437
4202	BF Goodrich CLM	6/20/83	16.22	0.01450	74	16.17	0.01445
4209	BF Goodrich Lifesaver XLM	6/20/83	11.27	0.01004	73	11.20	0.00998
4210	BF Goodrich Lifesaver XLM	6/20/83	10.68	0.00952	76	10.72	0.00955
4211	BF Goodrich Lifesaver XLM	6/20/83	10.82	0.00967	77	10.89	0.00973
4212	BF Goodrich Lifesaver XLM	6/20/83	11.02	0.00986	73	10.95	0.00979
4213	BF Goodrich Lifesaver XLM	6/20/83	11.01	0.00985	72	10.90	0.00975

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4214	BF Goodrich Lifesaver XLM	6/20/83	10.95	0.00980	76	10.99	0.00984
4215	Goodyear Arriva	6/21/83	11.85	0.01059	73	11.77	0.01052
4216	Goodyear Arriva	6/21/83	12.33	0.01104	73	12.25	0.01097
4217	Goodyear Arriva	6/21/83	12.06	0.01082	75	12.06	0.01082
4218	Goodyear Arriva	6/21/83	12.53	0.01121	76	12.57	0.01124
4219	Goodyear Arriva	6/21/83	12.06	0.01075	75	12.06	0.01075
4220	Goodyear Arriva	6/21/83	12.12	0.01080	75	12.12	0.01080
4221	Goodyear Cushion Belt Polyglas	6/21/83	15.13	0.01353	73	15.03	0.01344
4222	Goodyear Cushion Belt Polyglas	6/21/83	15.32	0.01370	75	15.32	0.01370
4223	Goodyear Cushion Belt Polyglas	6/21/83	15.39	0.01374	73	15.29	0.01365
4224	Goodyear Cushion Belt Polyglas	6/21/83	15.26	0.01364	77	15.36	0.01373
4225	Goodyear Cushion Belt Polyglas	6/21/83	15.61	0.01393	73	15.51	0.01383
4226	Goodyear Cushion Belt Polyglas	6/21/83	15.39	0.01372	75	15.39	0.01372

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4227	Goodyear Custom Polysteel	6/21/83	12.29	0.01097	75	12.29	0.01097
4228	Goodyear Custom Polysteel	6/21/83	12.09	0.01079	74	12.05	0.01075
4229	Goodyear Custom Polysteel	6/22/83	12.29	0.01094	77	12.37	0.01102
4230	Goodyear Custom Polysteel	6/22/83	12.50	0.01117	74	12.46	0.01113
4231	Goodyear Custom Polysteel	6/22/83	12.56	0.01120	76	12.60	0.01124
4232	Goodyear Custom Polysteel	6/22/83	12.29	0.01095	76	12.33	0.01099
4233	Goodyear Power Streak	6/22/83	16.07	0.01432	78	16.23	0.01446
4234	Goodyear Power Streak	6/22/83	15.41	0.01372	76	15.46	0.01377
4235	Goodyear Power Streak	6/22/83	15.99	0.01426	79	16.20	0.01445
4236	Goodyear Power Streak	6/22/83	15.25	0.01358	77	15.35	0.01367
4237	Goodyear Power Streak	6/22/83	16.06	0.01438	79	16.27	0.01457
4238	Goodyear Power Streak	6/22/83	16.05	0.01437	76	16.10	0.01442
4239	Goodyear Tiempo	6/22/83	13.36	0.01195	73	13.27	0.01187

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4240	Goodyear Tiempo	6/22/83	14.24	0.01269	73	14.15	0.01261
4241	Goodyear Tiempo	6/22/83	13.63	0.01216	72	13.50	0.01204
4242	Goodyear Tiempo	6/22/83	13.49	0.01208	73	13.40	0.01200
4243	Goodyear Tiempo	6/22/83	13.70	0.01221	76	13.75	0.01225
4244	Goodyear Tiempo	6/23/83	14.04	0.01254	74	13.99	0.01249
4245	Laramie Easy Rider	10/26/82	16.10	0.01436	77	16.21	0.01446
4246	Laramie Easy Rider	10/26/82	15.81	0.01414	76	15.86	0.01419
4247	Laramie Easy Rider	10/26/82	15.41	0.01373	72	15.26	0.01360
4248	Laramie Easy Rider	10/26/82	16.66	0.01486	74	16.61	0.01481
4249	Laramie Glass Rider	10/26/82	11.54	0.01029	72	11.43	0.01018
4250	Laramie Glass Rider	10/26/82	11.46	0.01026	75	11.46	0.01026
4251	Laramie Glass Rider	10/27/82	11.34	0.01013	75	11.34	0.01013
4252	Laramie Glass Rider	10/27/82	11.27	0.01004	76	11.31	0.01008
4253	Kelly-Springfield Benchmark	4/07/83	17.38	0.01549	76	17.44	0.01554
4254	Kelly-Springfield Benchmark	4/07/83	17.65	0.01577	77	17.77	0.01588

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4255	Kelly-Springfield Benchmark	4/08/83	17.88	0.01594	77	18.00	0.01604
4256	Kelly-Springfield Benchmark	4/08/83	15.94	0.01514	76	15.99	0.01519
4257	Kelly-Springfield Navigator	5/27/83	12.23	0.01092	72	12.11	0.01081
4258	Kelly-Springfield Navigator	5/27/83	11.89	0.01061	73	11.81	0.01054
4259	Kelly-Springfield Navigator	6/14/83	12.50	0.01115	73	12.42	0.01108
4260	Kelly-Springfield Navigator	6/15/83	12.09	0.01080	74	12.05	0.01077
4261	Kelly-Springfield Roadmark	4/08/83	15.23	0.01360	75	15.23	0.01360
4262	Kelly-Springfield Roadmark	4/08/83	15.91	0.01419	73	15.80	0.01410
4263	Kelly-Springfield Roadmark	4/11/83	15.83	0.01410	75	15.83	0.01410
4264	Kelly-Springfield Roadmark	5/26/83	15.49	0.01383	77	15.59	0.01392
4265	K-Mart Economizer	10/15/82	17.16	0.01529	78	17.33	0.01545

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4266	K-Mart Economizer	10/15/82	17.33	0.01550	77	17.44	0.01560
4267	K-Mart Economizer	10/15/82	17.47	0.01561	75	17.47	0.01561
4268	K-Mart Economizer	10/15/82	17.42	0.01554	78	17.59	0.01569
4269	K-Mart KM225	10/12/82	12.28	0.01093	76	12.32	0.01097
4270	K-Mart KM225	10/12/82	12.69	0.01133	75	12.69	0.01133
4271	K-Mart KM225	10/12/82	12.28	0.01094	75	12.28	0.01094
4272	K-Mart KM225	10/13/82	12.22	0.01093	78	12.34	0.01104
4273	K-Mart KM-78	10/20/82	18.00	0.01606	75	18.00	0.01606
4274	K-Mart KM-78	10/20/82	17.65	0.01573	76	17.71	0.01578
4275	K-Mart KM-78	10/20/82	18.15	0.01622	76	18.21	0.01627
4276	K-Mart KM-78	10/20/82	17.88	0.01596	73	17.76	0.01586
4277	Michelin XWW	7/06/82	11.89	0.01061	76	11.93	0.01064
4278	Michelin XWW	7/06/82	11.89	0.01061	76	11.93	0.01064
4279	Michelin XWW	9/25/82	11.69	0.01040	76	11.73	0.01043
4280	Michelin XWW	9/26/82	11.68	0.01042	75	11.68	0.01042
4281	Michelin XWW	9/26/82	11.68	0.01043	75	11.68	0.01043

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4282	Michelin XWW	9/26/82	11.68	0.01041	77	11.76	0.01048
4283	Michelin XVS	9/23/82	14.75	0.01381	76	14.80	0.01386
4284	Michelin XVS	9/23/82	14.61	0.01368	76	14.66	0.01372
4285	Michelin XVS	9/25/82	14.54	0.01358	77	14.64	0.01367
4286	Michelin XVS	9/23/82	14.54	0.01354	77	14.64	0.01363
4287	Montgomery Ward Grappler All-Season	6/15/83	13.93	0.01245	78	14.07	0.01257
4288	Montgomery Ward Grappler All-Season	7/06/82	13.77	0.01228	78	13.91	0.01241
4289	Montgomery Ward Grappler All-Season	7/06/82	13.90	0.01240	79	14.08	0.01256
4290	Montgomery Ward Grappler All-Season	7/06/82	14.31	0.01277	80	14.55	0.01298
4291	Montgomery Ward Road Guard	7/13/82	16.16	0.01442	78	16.32	0.01456
4292	Montgomery Ward Road Guard	7/13/82	16.16	0.01440	79	16.37	0.01459
4293	Montgomery Ward Road Guard	7/13/82	15.76	0.01406	77	15.86	0.01415

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4294	Montgomery Ward Road Guard	7/13/82	16.22	0.01446	77	16.33	0.01455
4295	Montgomery Ward Runabout All-Season	7/07/82	11.86	0.01056	78	11.98	0.01067
4296	Montgomery Ward Runabout All-Season	7/08/82	11.73	0.01045	75	11.73	0.01045
4297	Montgomery Ward Runabout All-Season	7/08/82	12.06	0.01075	75	12.06	0.01075
4298	Montgomery Ward Runabout All-Season	7/08/82	11.72	0.01045	76	11.76	0.01048
4299	Michelin XVS	9/23/82	14.47	0.01351	78	14.61	0.01364
4300	Michelin XVS	9/25/82	14.61	0.01364	75	14.61	0.01364
4301	Multi-Mile Poly IV	9/15/82	18.47	0.01648	73	18.35	0.01637
4302	Multi-Mile Poly IV	9/14/82	18.48	0.01651	78	18.66	0.01668
4303	Multi-Mile Poly IV	9/14/82	18.41	0.01642	78	18.59	0.01659
4304	Multi-Mile Poly IV	9/14/82	18.29	0.01634	77	18.41	0.01645
4305	Multi-Mile Supreme	9/13/82	12.24	0.01092	78	12.36	0.01103
4306	Multi-Mile Supreme	9/13/82	12.51	0.01116	78	12.63	0.01127
4307	Multi-Mile Supreme	9/13/82	12.24	0.01095	74	12.20	0.01091

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4308	Multi-Mile Supreme	9/13/82	12.11	0.01083	77	12.19	0.01090
4309	Multi-Mile XL	9/15/82	11.56	0.01033	76	11.60	0.01036
4310	Multi-Mile XL	9/15/82	11.64	0.01040	74	11.60	0.01037
4311	JC Penney Mileagemaker XP	7/08/82	13.12	0.01170	78	13.25	0.01182
4312	JC Penney Mileagemaker XP	7/08/82	12.58	0.01122	76	12.62	0.01126
4313	JC Penney Mileagemaker XP	7/08/82	12.98	0.01157	76	13.02	0.01161
4314	JC Penney Mileagemaker XP	7/08/82	12.98	0.01157	76	13.02	0.01161
4315	JC Penney Mileagemaker Plus	7/06/82	11.92	0.01065	78	12.04	0.01076
4316	JC Penney Mileagemaker Plus	7/07/82	12.13	0.01081	77	12.21	0.01088
4317	JC Penney Mileagemaker Plus	7/07/82	11.99	0.01069	76	12.03	0.01072
4318	JC Penney Mileagemaker Plus	7/07/82	12.26	0.01097	76	12.30	0.01100
4319	Sears Guardsman	7/09/82	16.78	0.01500	77	16.89	0.01509

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4320	Sears Guardsman	7/09/82	16.38	0.01464	77	16.49	0.01473
4321	Sears Guardsman	7/09/82	16.65	0.01484	77	16.76	0.01494
4322	Sears Guardsman	7/09/82	15.55	0.01387	78	15.70	0.01401
4323	Sears Guardsman	7/09/82	16.86	0.01504	77	16.97	0.01514
4324	Sears Guardsman	7/09/82	16.51	0.01471	78	16.67	0.01486
4325	Sears Road Handler 78	7/09/82	13.03	0.01162	78	13.16	0.01174
4326	Sears Road Handler 78	7/13/82	13.16	0.01174	75	13.16	0.01174
4327	Sears Road Handler 78	7/13/82	13.17	0.01177	76	13.21	0.01181
4328	Sears Road Handler 78	7/13/82	13.17	0.01179	77	13.26	0.01187
4329	Sears Road Handler 78	7/13/82	13.30	0.01185	76	13.34	0.01189
4330	Sears Road Handler 78	7/13/82	13.23	0.01182	77	13.32	0.01190
4331	Sears Super Guard	7/08/82	15.86	0.01414	77	15.96	0.01423
4332	Sears Super Guard	7/08/82	15.99	0.01424	78	16.15	0.01438
4333	Sears Super Guard	7/08/82	15.30	0.01365	78	15.45	0.01378
4334	Sears Super Guard	7/09/82	15.86	0.01414	77	15.96	0.01423
4335	Sears Super Guard	7/09/82	15.78	0.01408	79	15.99	0.01426

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4320	Sears Guardsman	7/09/82	16.38	0.01464	77	16.49	0.01473
4321	Sears Guardsman	7/09/82	16.65	0.01484	77	16.76	0.01494
4322	Sears Guardsman	7/09/82	15.55	0.01387	78	15.70	0.01401
4323	Sears Guardsman	7/09/82	16.86	0.01504	77	16.97	0.01514
4324	Sears Guardsman	7/09/82	16.51	0.01471	78	16.67	0.01486
4325	Sears Road Handler 78	7/09/82	13.03	0.01162	78	13.16	0.01174
4326	Sears Road Handler 78	7/13/82	13.16	0.01174	75	13.16	0.01174
4327	Sears Road Handler 78	7/13/82	13.17	0.01177	76	13.21	0.01181
4328	Sears Road Handler 78	7/13/82	13.17	0.01179	77	13.26	0.01187
4329	Sears Road Handler 78	7/13/82	13.30	0.01185	76	13.34	0.01189
4330	Sears Road Handler 78	7/13/82	13.23	0.01182	77	13.32	0.01190
4331	Sears Super Guard	7/08/82	15.86	0.01414	77	15.96	0.01423
4332	Sears Super Guard	7/08/82	15.99	0.01424	78	16.15	0.01438
4333	Sears Super Guard	7/08/82	15.30	0.01365	78	15.45	0.01378
4334	Sears Super Guard	7/09/82	15.86	0.01414	77	15.96	0.01423
4335	Sears Super Guard	7/09/82	15.78	0.01408	79	15.99	0.01426

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4336	Sears Super Guard	7/09/82	15.99	0.01430	76	16.04	0.01435
4337	Sears Weather Handler	7/07/82	13.73	0.01225	78	13.87	0.01237
4338	Sears Weather Handler	7/07/82	13.26	0.01182	79	13.44	0.01197
4339	Sears Weather Handler	7/07/82	13.87	0.01237	77	13.96	0.01245
4340	Sears Weather Handler	7/07/82	13.66	0.01219	77	13.75	0.01227
4341	Sears Weather Handler	7/07/82	13.79	0.01230	77	13.88	0.01238
4342	Sears Weather Handler	7/07/82	13.26	0.01181	78	13.39	0.01192
4343	Multi-Mile XL	9/15/82	12.11	0.01080	77	12.19	0.01087
4344	Multi-Mile XL	9/15/82	11.83	0.01054	76	11.87	0.01058
4345	Summit Steel	10/12/82	13.43	0.01196	75	13.43	0.01196
4346	Summit Steel	10/12/82	12.68	0.01132	74	12.64	0.01128
4347	Summit Steel	10/12/82	13.15	0.01175	74	13.11	0.01171
4348	Summit Steel	10/12/82	13.43	0.01202	75	13.43	0.01202
4349	Summit Supreme 120	10/07/82	16.98	0.01519	74	16.92	0.01514
4350	Summit Supreme 120	10/07/82	17.29	0.01545	73	17.18	0.01535
4351	Summit Supreme 120	10/07/82	17.33	0.01550	79	17.56	0.01571

Rolling Resistance Test Results for Individual Tires

EPA ID#	Mfr/Brand & Model	Test Date	RR Force (lbf)	RRC	Ambient Temp. (°F)	Temperature-Corrected RR Force (lbf)	Temperature-Corrected RRC
4352	Summit Supreme 120	10/07/82	17.60	0.01569	77	17.72	0.01579
4357	Uniroyal Fastrak Poly	12/09/83	17.83	0.01596	75	17.83	0.01596
4358	Uniroyal Fastrak Poly	12/09/83	18.78	0.01683	70	18.47	0.01655
4359	Uniroyal Fastrak Poly	12/09/83	18.66	0.01665	75	18.66	0.01665
4360	Uniroyal Fastrak Poly	12/09/83	19.58	0.01744	74	19.52	0.01738
4361	Uniroyal Steeler	6/23/83	11.18	0.01000	76	11.22	0.01003
4362	Uniroyal Steeler	6/23/83	11.50	0.01026	77	11.58	0.01033
4363	Uniroyal Steeler	6/23/83	10.76	0.00962	75	10.76	0.00962
4364	Uniroyal Steeler	6/23/83	11.65	0.01043	77	11.73	0.01050
4365	Uniroyal Steeler	6/23/83	10.44	0.00933	78	10.54	0.00942
4366	Uniroyal Steeler	6/23/83	11.38	0.01018	77	11.46	0.01025
4367	Uniroyal Tiger Paw	6/23/83	11.77	0.01054	78	11.89	0.01064
4368	Uniroyal Tiger Paw	6/24/83	11.79	0.01054	73	11.71	0.01047
4369	Uniroyal Tiger Paw	6/24/83	11.78	0.01053	77	11.86	0.01060
4370	Uniroyal Tiger Paw	6/24/83	12.39	0.01106	75	12.39	0.01106